E/CONF.39/C/454
3 Nov.1962
ORIGINAL : ENGLISH

UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: C.3.2

United States of America

TRANSFORMING IRRIGATION FROM AN AGE-OLD ART INTO A MODERN SCIENCE THROUGH RESEARCH AND TECHNOLOGY

By Robert M. HAGAN,
Chairman,
Department of Irrigation,
University of California,
Davis, California

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

NOTES

1. Papers selected for inclusion in General Sessions will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

2. Papers selected for inclusion in Specialized Sessions will be available at the Conference in only one of the above official languages.

3. Summaries of all papers, as submitted by contributors, will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

4. Papers and summaries will not be available for general distribution in advance of the Conference. They will be published in advance in limited quantities only for the use of delegations of participating governments and of other authorized participants. Post-Conference publication and general distribution of the Conference Proceedings will follow United Nations practices as laid down by the United Nations Publications Board.

TRANSFORMING IRRIGATION FROM AN AGE-OLD ART INTO A MODERN SCIENCE THROUGH RESEARCH AND TECHNOLOGY

by Robert M. Hagan
Chairman, Department of Irrigation
University of California, Davis, California

1. Economic and social development of many areas is dependent upon achieving increased agricultural production. This often requires the opening of additional lands to agriculture through new irrigation projects and also the improvement of existing irrigation systems to insure efficient water use and continued productivity of irrigated lands. A recent report 1/ of the Food and Agriculture Organization of the United Nations suggests that: "...improved water management (including irrigation and drainage practices) can probably do more towards increasing food supplies and agricultural income in the irrigated areas of the world than any other agricultural practice." Science and technology are now advanced enough, if properly integrated and summarized, to transform irrigation from an age-old art into a modern science capable of providing the basis for productive irrigation projects.

2. Irrigation was extensively practiced by the earliest civilizations known. Remnants of dams, canals and other structures testify to the extensive practice of the art of irrigation among the ancient peoples. Much of this irrigated agriculture ultimately failed because of technical problems created by incomplete planning and by misuse of watershed areas, soils and water. These problems include failing water supply, erosion and siltation of water storage and conveyance structures, excessive applications of irrigation water, leaching of soil nutrients, rising groundwater tables and waterlogging of soil, and ultimately accumulation of toxic salts. Unfortunately these same problems continue to cause the failure of some recently established irrigation projects, reduce crop yields far below potential productivity, and create economic and social unrest which so often accompany slowly developing and unproductive irrigation projects. In some areas food production lost through deterioration of irrigated lands is estimated to offset production from additional lands being brought into production under new irrigation schemes.

3. The development of water supplies may involve construction of impressive and ultra-modern engineering structures, but the developed water is often conveyed through inefficient distribution systems to farmers who continue to irrigate in accordance with age-old practices and traditions little influenced by modern science and technology. Actually, new or improved irrigation projects should not be considered as complete until scientifically sound and well-engineered provisions have been made to apply water efficiently to the last crop row on the last farm and adequate arrangements made to remove any surplus water wherever necessary. Intelligent application of today's knowledge of irrigation science and technology would accelerate the effective utilization of water and soil resources in developing areas, achieve maximum crop production from available water supplies, insure an abundant and permanently successful irrigation agriculture, and reclaim many previously productive lands now waterlogged and often salinized.

1/ Houston, C. E., Recommendations for Improved Water Management Programs, Food and Agriculture Organization, Rome, unnumbered mimeo. (1962).

4. The modern science of irrigation, in a broad sense, must seek to increase the efficiency of converting rain or other precipitation into useable water and to reduce all losses in utilizing this water. FIGURES I and II illustrate some of the elements in the water-supply and water-utilization systems and some of the sources of water loss. Each loss represents a challenge to the irrigation scientist and engineer to seek economic means for its reduction or elimination.

5. Since modern science and technology are now generally employed in construction of water supply projects, this paper will concentrate on opportunities to use present knowledge for increasing the effectiveness of man's utilization of developed water supplies. This requires the skillful combination of accumulated knowledge in many professional fields including engineering, soil science, plant science, and agricultural economics. Difficulties in obtaining and coordinating the knowledge from the many professional disciplines involved contribute to serious problems encountered in planning and operating many irrigation schemes.

6. Irrigation needs and practices vary widely. This complicates the planning of new irrigation projects and also the operation of existing irrigation systems and irrigated farms. One important aspect of science is the ability to predict what results can be expected in given situations. Mankind in general, and particularly the less developed countries, can ill-afford the time-wasting, resource-depleting, and disappointing process of trial-and-error and inadequately planned local trials. With the gradual development of modern irrigation science, basic irrigation principles are emerging which can serve as valuable guides in predicting irrigation requirements and potential problems. Now available in both the developed and developing countries are much knowledge and methodology for evaluating irrigation sites, determining the suitability of proposed irrigation waters, estimating irrigation requirements of crops, predicting the effects of specific irrigation practices and related farm operations on given crops under prevailing site conditions, diagnosing drainage needs, and estimating leaching requirements to maintain favorable salt balances. Considerable information is also available on the tremendously important interrelations between irrigation, fertilization, tillage, and other crop production practices.

7. The success of any agriculture, especially an irrigated agriculture, is dependent upon the soil. Modern methods of soil survey and land classification provide an essential inventory and summary of soil characteristics. Soil investigations should include textural and structural conditions of soil profile, infiltration and and hydraulic conductivity, water retention characteristics, nutrient status, salinity, etc. Such modern instrumentation as pressure plate and pressure membrane apparatus, flame photometers, pH-meters, and electrical conductivity meters are available to aid in quickly appraising soil properties. Although there is a great need for further development of such measurements, present knowledge and instrumentation permit reasonably accurate prediction of soil behavior under irrigation and should avoid the economic and social tragedies arising from developing and settling people on lands unsuited to irrigation farms.

8. Investigations of water supplies to be used for irrigation should include considerations of both quantity and quality (content of dissolved or suspended materials). Research by the U.S. Salinity Laboratory 2/ and other agencies provide valuable guidance in predicting the effects of given waters on soil properties and ultimately on crop production. Methods and instruments developed by the Salinity Laboratory are now used in many countries for water analysis and prediction of irrigation suitability. However, for accurate prediction, information on climatic conditions of the area (evaporation and rainfall), soil properties (including clay minerals), irrigation method, drainage conditions, and crops to be grown must also

2/ Richards, L. A. (editor), Diagnosis and Improvement of Saline and Alkali Soils, U. S. Department of Agriculture, Agric. Handbook No. 60. (1954).

be considered in addition to water analysis data. Water quality considerations will become increasingly important as more complete utilization is made of available water supplies.

9. Vital for planning, operations, and the ultimate success of an irrigation project is reliable information on consumptive use of water by different crops as well as the seasonal and annual variations in these requirements. Such data provide the basis for selection, construction, and operation of storage structures, conveyance and distribution networks, and irrigation systems. Consumptive use should also be a major factor in selecting crops to be grown in water-deficient areas. It has become a highly important factor in arbitration of controversies over river systems both within and between nations.

10. Consumptive use is difficult to measure directly. Research in the United States and Europe has developed methods for utilizing climatic data for estimating consumptive use. Formulae proposed by Penman, Thornthwaite, Turc. Lowry-Johnson, and Blaney-Criddle are widely used and, unfortunately, sometimes misused. The simpler, but more empirical formulae, are satisfactory only if the local correction factors, which are substantial, are known. The extensive investigations correlating water evaporation from standard pans with consumptive use may be useful, but they also require knowledge of required correction factors. Although much more research is needed, present knowledge intelligently applied could provide the basis for wise selection of crops and more efficient planning and operation of irrigation projects and systems.

11. The gross effects of deficient and of excessive soil water on plant growth are well known, but there has been much controversy about specific irrigation practices required to produce a desired level of crop production. Some irrigation specialists have advocated relatively infrequent irrigation, while others have favored keeping the soil quite wet. Many agriculturalists, knowing that water is essential for crop growth, assume that the more irrigation water applied, the higher the crop yield obtained. This belief leads many farmers to irrigate with unnecessary frequency and with a great waste of water--thus leaching plant nutrients and aggravating drainage problems.

12. Since water, especially in the arid regions, is a limiting and usually a costly resource, it is generally desirable to plan irrigation programs for "efficiency" in terms of maximizing crop yield per unit of water applied. In some cases it may be preferable to maximize crop yield per unit of irrigated land or per unit of initial investment in land preparation or irrigation distribution system. Thus the most desirable irrigation practice will vary with the situation and depend upon proper integration of all factors involved. Efforts 3/, 4/ are now being made to formulate some general irrigation principles useful in determining irrigation practices. The practices to be recommended should be based on sound irrigation principles and should be designed specifically in accordance with prevailing soil, crop, climate, management and economic factors. Irrigation practices should not be merely copied from irrigation practices reported as successful elsewhere without carefully comparing all factors involved. It should be emphasized that a permanently successful irrigation agriculture requires that the irrigation, fertilization and other cultural practices be carefully tailored to match local conditions.

3/ Israelsen, O. W. and Hansen, V. E., Irrigation Principles and Practices, John Wiley and Sons, New York-London. (1962).

4/ Hagan, R. M. and Vaadia, Y., Principles of Irrigated Cropping, UNESCO Arid Zone Research Proceedings, Plant-Water Relations Symposium, pp. 215-225, Madrid. (1959).

13. Detailed research on the effects of irrigation on the physiology of the cotton plant (carried out at the Cotton Research Station at Shafter, California by scientists of the U.S. Department of Agriculture and the University of California) may help answer some baffling problems encountered with irrigated cotton in developed and developing countries. For example, recent investigations 5/ made by a scientist from California, while serving as an expert with FAO, suggest that much of the severe loss of cotton production experienced in the United Arab Republic (Egypt) in 1961, which gravely affected the financial position of that country, was likely caused by irrigation practices which, although traditional, were not favorable to the cotton plant under the climatic conditions of this year. He believes adverse irrigation practices and resultant unfavorable drainage were more responsible for the crop loss than the so-called "reddening" disease or insect infestations. It is estimated that application of recent research on cotton irrigation could increase U.A.R.'s cotton yield nearly 50% or about 250 million dollars per year at today's prices while at the same time permitting substantial savings in irrigation water and reducing drainage requirements.

14. Research on crop irrigation reveals many opportunities to influence the development of crop plants so as to best serve man's needs. Studies in the United States showing possibilities for increasing the percentage of sugar in maturing sugar beets by withholding irrigation are now being successfully applied in Israel with important savings of water in this arid country. Research demonstrating the critical periods in the water relations of maize, when combined with better varieties and improved cultural practices, now permits this grain to augment the food resources of Central and South America, Africa and India.

15. To take full advantage of available research on irrigation of crops, water must be conveyed to the farmers' fields and spread in accordance with the water requirements of the crop and soil characteristics. Many countries are tolerating appalling wastes of water in conveyance, distribution, and application losses. Leached soils, high groundwater tables, and salinity are the unfortunate consequences of such losses. The poorly controlled application of irrigation water shown in FIGURE III is unfortunately still a common sight in both developed and less-developed countries. Contrast FIGURE III with the neatly graded contour furrows of FIGURE IV which permit much more efficient irrigation with less labor.

16. The irrigation method to be used should be carefully selected in accordance with topography, soil, rate of water delivery, drainage hazards, the crop and its consumptive use, water quality, salinity, and other considerations. If conditions favor use of sprinkler systems, they must be designed correctly and used under the conditions for which they were designed. If conditions favor surface irrigation --either border, furrow, corrugations, basins, or controlled flooding--the land must be topographically surveyed, graded, and the correctly computed size of head ditch or pipeline determined. The proper length of run, width of border, or size of basin must be selected, but this is most difficult. Because of variability in rates of water intake into soils and other factors, the irrigation engineer must still depend partially on local experience and trial-and-error methods. However, the engineer's art is now being supplemented by scientific research which is providing methods for more accurate prediction of irrigation system performance. Considerable information is available on land grading and on selecting, designing, and operating different irrigation systems in publications issued by the U.S. Department of Agriculture and University Agricultural Experiment Stations. A pamphlet on grading land for surface irrigation 6/ prepared in California has now been reprinted by other countries in

5/ Walhood, B. T., Report to Government of U.A.R. on Physiologic Problems in Cotton, FAO, Division of Plant Production, Mimeo., (in press).

6/ Marr, J. C., Grading Land for Surface Irrigation, University of California Agricultural Experiment Station and Extension Service, Circular 438 (1957).

French, Greek and Spanish and is extensively used by developing countries.

17. Very efficient, but expensive, machines are now available to grade land for irrigation. In many cases these large and costly machines are not suitable for use in developing countries. The activities of an U.S.A.I.D. irrigation specialist working in India, Mr. George C. Knierim, demonstrate the successful application of sound principles of irrigation system design simplified to meet local conditions and carried out using very simple and inexpensive land grading tools made by a village blacksmith or the farmer himself from local materials. Buck scrapers, ridgers, corrugators, furrowers, and cultivators have been built by adapting tools used by the Mormon and other pioneers in the American West. It is estimated that some 60% of all water supplied for irrigation in India is lost. Water lost on improperly prepared fields constitutes a major loss. As shown in FIGURE IV, Mr. Knierim and his Indian associates are now able to grade fields for efficient irrigation and drainage, even on difficult soils and terrain, thus boosting the productivity of the land often by as much as four- or six-fold. With improved water management, salinity hazards are greatly reduced. His advice: sound principles, simple methods, and simple tools. This work illustrates that the conversion of irrigation from art into a science need not be dependent upon costly imported equipment.

18. Modern technology now produces an array of materials and equipment to control seepage, possibly reduce evaporation, and regulate flow in canals, distributaries, and on fields. Although some materials and equipment are relatively expensive, their use by less developed countries to conserve water, stimulate crop production, and avoid water-logging should be seriously considered. Some water control equipment can be produced inexpensively from local materials. FIGURE V shows an inexpensive and locally made canvas dam being used in India to hold water in irrigation ditches, and FIGURE VI shows simple spiles employed in Jordan to control effectively the flow of water from a forebay into furrows. Very satisfactory spiles can be easily cut from bamboo in many tropical countries.

19. Siphons are now often used to deliver water from a supply ditch over its bank and onto the land. They permit easy control of water, eliminate cutting ditch banks, greatly facilitate ditch maintenance, and provide much more accurate control of quantities of water being applied. They can be easily constructed out of metal, plastic or rubber. Flow tables for different siphon sizes and operating heads are readily available and have been reproduced in many countries.

20. An age-old practice in Egypt, improved by modern scientific analysis at the U.S. Salinity Laboratory 7/, now provides a clever means of reducing salt damage to germinating seedlings. By special shaping of seedbeds and furrows causing salt to accumulate away from seed rows, salt concentration around germinating seeds may be greatly reduced, permitting emergence of a good stand even in the presence of saline soils and irrigation waters.

21. No irrigation project should be conceived or operated without attention to possible drainage requirements. Although the art of drainage is probably as old as agriculture itself, the need for drainage is still frequently overlooked. Painstaking research by mathematicians, soil physicists, and engineers has produced in the last 20 years effective means for analyzing the causes of drainage problems, predicting required capacities, and selecting the optimum depth and spacing of drains. Soil chemists have developed guides for computing the amount of water which should pass through soils to leach salts and maintain favorable salt balances. Thus engineers now have a valuable body of scientific knowledge to guide them in drainage system design and operations.

7/ Bernstein, L., Fireman, M., and Reeves, R. C., Control of salinity in the Imperial Valley, California, U.S. Dept. of Agriculture, ARS-41-4 (1955).

22. The irrigated plains of the Indus River and its tributaries in West Pakistan constitute one of the most difficult irrigation and drainage problem areas of the world. Today, waterlogging and salinity are causing approximately 100,000 acres to go out of agricultural production each year. Additional large areas are partially affected by inadequate drainage and salts which have together reduced crops yields to levels of only 30 to 50% of those in comparable well-drained non-saline soils.

23. The attack now being made on this enormous problem by a special United States team of scientists and engineers[8/], working under agreements with the Republic of Pakistan, provide a striking example of the application of modern science and technology to the solution of complex and vast irrigation and drainage problems. This team is employing mathematical model techniques and high-speed digital computers to study the feasibility of using tubewells to drain the Indus area and provide a water management program which will permit restoration of a productive agriculture. More specifically, they seek: (1) to evaluate choices between water management designs involving different combinations of tubewells, surface drains, subsurface drains, and canal lining with sealants; (2) to determine the optimal number, spacing and depth of tubewells for irrigation project areas, and to identify the optimal schedule of pumping water for crops or to drains during the year to maximize agricultural productivity and to control the salinity of the irrigation water: and (3) to study the mechanism of the salt balance including leaching from root zones, movement of salts in the ground water, interactions between adjacent regions arising from discharge of brine to the waterways, and the magnitude of the salt accumulation in aquifers during the next 50 years. Another general objective is to test and demonstrate the use of modern techniques of systems analysis and electronic computers for economic and engineering analysis, as a basis for planning and design of irrigation and drainage systems.

24. Many irrigation specialists who have studied the problems of the Indus Plain over the past 20 years assumed that the waterlogging and salinity problems were caused by canal seepage and over-irrigation. Accordingly, most specialists have suggested lining canals and reducing excessive irrigation. By using a fresh scientific approach to an old and difficult problem, new solutions have been proposed. In brief, these new techniques indicate for this area that: (1) tubewell systems can effectively eliminate waterlogging and salinity in large areas of West Pakistan although several test well projects during the past 15 years have not been encouraging; (2) tubewells can provide an important supplemental water supply for increasing agricultural production on the Indus Plain; and (3) the lining of canals to retard seepage cannot be justified under present costs in this area. The computer also provides data on optimal spacing and depth of wells and on pumping programs for wells to maintain salinity within tolerable limits.

25. As illustrated by this Pakistan study, mathematical models, digital computers, and other techniques under development can give the irrigation scientist and engineer powerful new tools to hasten the progress of irrigation from an art into a fully modern science. These new techniques permit rapid and accurate consideration of a vast spread of hydro-agronomic conditions and of technological possibilities in order to formulate corresponding responses corrected, as necessary, for "feed-back" relations. These techniques are not merely problem-solving tools; they are perhaps even more useful as problem-identification tools. By synthesizing the best available data in a theoretical construct, even though

8/ Information on West Pakistan project from preliminary statement by Professor Harold A. Thomas, Jr. for later inclusion in Draft Report of White House-Interior Panel on Waterlogging and Salinity of West Pakistan. For more complete discussion of these techniques, see Maass, A. et al, Design of Water Resource Systems, Harvard University Press, Cambridge, Massachusetts. (1962).

incomplete, it is possible with error analysis to show quantitatively the effect upon practical conclusions of the inadequacy of certain planning data and also the cost of having to base decisions on poor rather than good data. With the multiplicity of variables and inter-actions involved in irrigation and drainage projects, the simulated results yield a rational basis for evaluating the relative importance of variables and of types of data obtainable from field and laboratory observations. This permits problem-identification. It also provides the irrigation specialist with valuable guidance for selecting data to be collected as the basis for planning, operations, and long range predictions. Such techniques add much to the modern science of irrigation.

26. Man has within his grasp the means to insure a highly productive and permanently successful agriculture, if full advantage is taken of opportunities now available to transform the art of irrigation into a modern science. Useful aids in doing this are Monographs on Irrigation[9] (in preparation), Drainage[10], and Salinity[11] which summarize research in these subject areas. An FAO-UNESCO Sourcebook[12] is also being written. These detailed Monographs and the more general Sourcebook should provide irrigation scientists and engineers with valuable guidance. Man's goals of more favorable living standards in this increasingly populous world can be met much more quickly both by increased utilization of the world's science and technology and by more effective cooperation between engineers, soil and crop scientists, and other professional groups whose combined efforts are needed to attain an abundant and permanently successful irrigation agriculture.

9/ Hagan, R.M., Haise, H.R., and Edminster, T.W. (editors), Irrigation of Agricultural Lands, American Society of Agronomy Monographs Series, (in preparation).

10/ Luthin, J. N. (editor), Drainage of Agricultural Lands, American Society of Agronomy Monographs, Vol. VII, Madison, Wisconsin (1957).

11/ Richards, L.A. (editor), Diagnosis and Improvement of Saline and Alkali Soils, U. S. Department of Agriculture, Agric. Handbook No. 60 (1954). Note: a revised edition is in preparation.

12/ Kovda, V., Hagan, R. M., and van den Berg, C. (editors), FAO-UNESCO International Sourcebook on Irrigation and Drainage of Arid Lands in Relation to Salinity and Alkali, (in preparation; to be published by FAO and UNESCO).

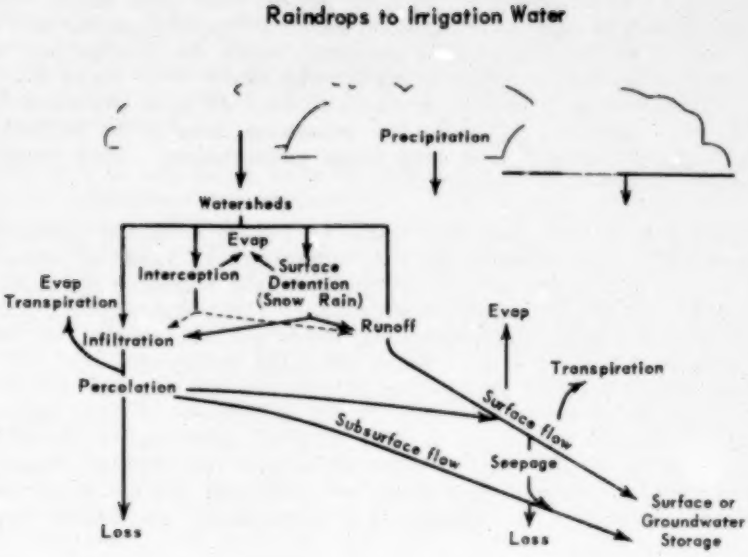

Fig. I Sources of Losses in converting precipitation to irrigation water.

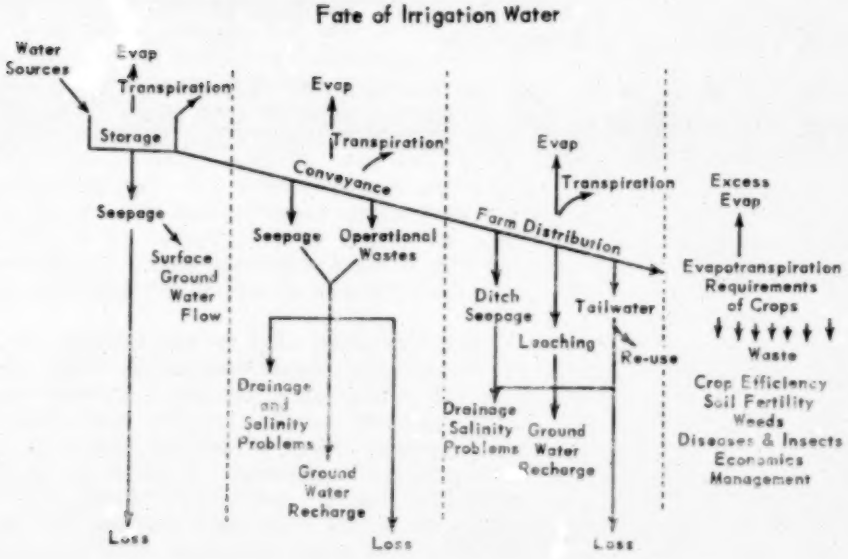

Fig. II Water losses in storage, conveyance, distribution and crop growth

Fig. III -

Inadequately prepared field makes efficient irrigation difficult

Fig. IV -

Graded contour furrows for efficient irrigation and drainage (India)

Fig. V -

Inexpensive canvas to control water in ditches (India)

Fig. VI -

Head-ditch, forebay, and spiles for control of water to furrows (Jordan)

1584 E - Nov.1962 - 1,600